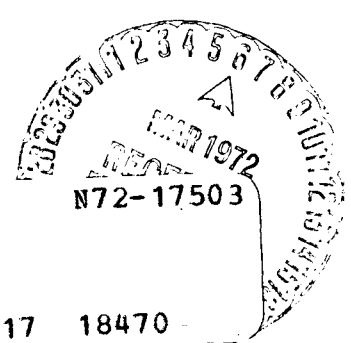
SOME CHARACTERISTICS OF THE CAVITATION EROSION OF METALS IN LIQUID OXYGEN

Yu. Ye. Krot, D. N. Bol'shutkin, V. V. Gavranek

Translation of: "Nekotoryye osobennosti kavitatsionnoy erozii metallov v zhidkom kislorode", Fiziko-khimicheskaya mekhanika materialov, Vol. 5, No. 2, pp. 214-217, 1969.

KIEV



NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546 FEBRUARY 1972

SOME CHARACTERISTICS OF THE CAVITATION EROSION OF METALS IN LIQUID OXYGEN

Yu. Ye. Krot, D. N. Bol'shutkin, V. V. Gavranek*

ABSTRACT. The cavitation action of liquid oxygen and water on metals with various lattice arrangements was studied: lead, copper, nickel, iron and zinc. The high resistance of iron and zinc to the cavitation action of oxygen was revealed. The resistance of lead, copper and nickel in cavitizing oxygen did not increase in comparison with their resistance in cavitizing water. There was no oxidation of the metals during tests in oxygen.

The development of modern mechanical engineering and cryogenic technology /214** has created an interest in studying the cavitation resistance of materials and the nature of cavitation damage in various liquids and in a wide range of temperatures. Of special importance is the study of cavitation erosion of materials in cryogenic liquids resulting from the low temperature of the materials they contain and degassing of a number of cryogenic liquids. The literature contains no information on such studies. The purpose of this work is to study the characteristics of the cavitation action of cryogenic liquids on metals with various lattice arrangements. Because of this factor, the metals are characterized by different laws governing mechanical property changes in cooling to -106° C.

It is known [1] that the collapse of cavitation bubbles is retarded by vapor and gas inside them. The intensity of shock waves which develop when

---

*Physical-Technical Institute of Low Temperatures. AN Ukrainian SSR, Kharkov.

**Numbers in the margin indicate the pagination in the original foreign text.

cavitation bubbles collapse in cryogenic liquids can exceed the intensity of shock waves in water, which are most active of many liquids in this respect [1]. The strong microshock effect of cryogenic liquids occurs because, as compression begins, the cavitation bubbles contain only vapor. This can be condensed, resulting in more rapid compression of the bubble. However, in cryogenic liquids, unlike water, the interval between the boiling point and the critical point is small (in nitrogen it is approximately five times smaller than in water, and in oxygen — four times smaller). As a result, condensation of vapor in the bubble can be incomplete during compression. The remaining vapor becomes a gas damper. Therefore, considerable microshock effect during cavitation can be expected from cryogenic liquids cooled to temperatures much lower than the boiling point.

It is most simple to cool oxygen: immersion of an operating chamber with oxygen into liquid nitrogen reduces the vapor pressure of the oxygen to 151 mm Hg (the operating chamber must be hermetically sealed to prevent air condensing inside). Moreover, certain physical characteristics of oxygen (surface tension, density) give it greater cavitation activity in comparison with other cryogenic liquids.

Cavitation in oxygen was excited by ultrasonics. The vibration source was a PMS-7 magnetostrictive vibrator, equipped with a supplemental cylindrical wave guide and fed from an ultrasonic generator UZG-10. Vibration frequency was 20 kHz; vibration amplitude was 15 μ. A sample of the material being studied was placed in a special holder at a distance about 1 mm from the end of the emitter; the holder was fastened in a nodal plane.

Study material consisted of technically pure lead, copper, nickel, iron and zinc. Before testing, all samples were polished and the samples of nickel, iron and zinc were annealed in a vacuum. Characteristics of the surface of the metals before testing are given in the table. Cavitation resistance was evaluated by the weight loss of the samples. For comparison, the above-mentioned metals were also tested in water at 60° C, as vapor tension of water

at this point is the same as in oxygen at -196° C. Damage to materials in water at this temperature is close to maximum [1].

Cavitation resistance of metals in oxygen and in water is illustrated in Figure 1. The curves have a comparatively steep beginning section; this can be related to defects on the surfaces of the samples, the elimination of which is preceded by a so-called incubation period [2]. Damage to lead in oxygen is so great that the weight loss of this sample cannot be shown on the general diagram. After 30 seconds, weight loss was 7.1 mg; after 5 minutes — 173 mg. Individual damage centers are surrounded by displacement lines (Figure 2), indicating that damage is preceded by plastic deformation. In water, the weight of the lead sample decreased 2.6 mg in 30 seconds, and with longer action, the plastic bulge of the surface of the sample eliminated the gap between the sample and the emitter, preventing testing with a fixed gap.

/215

/216

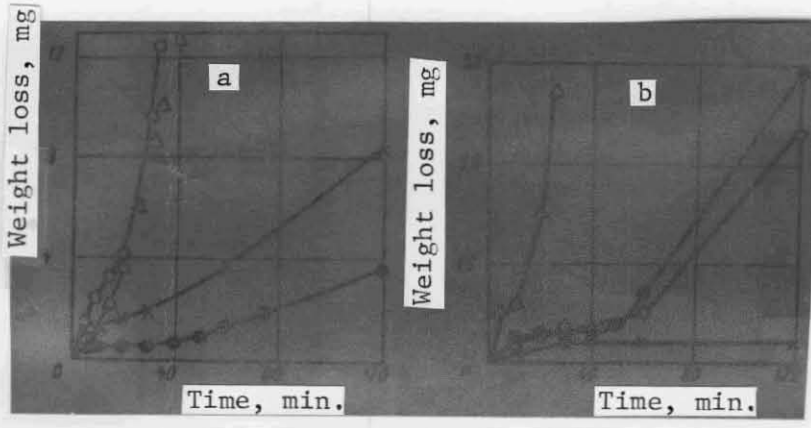


Figure 1. Resistance of metals during the cavitation action of oxygen (a) and water (b):
Δ - copper; O - zinc; ● - nickel; X - iron

The great difference in the degree of erosion of lead during the cavitation action of oxygen and water can be explained by the fact that weakening processes are observed in the effect of water on lead, and they are practically nonexistent in oxygen. Therefore, in oxygen, damage follows plastic deformation sooner. This is supported by microhardness studies.

Metal	T, °C	σ_B, kg/mm^2 [4], [5]	σ_τ, kg/mm^2 [4], [5]	Size of grain mm	Micro-hardness kg/mm2	Erosion rate mg/hr
Lead	+20	2	-	0.15	5	312
	-184	4.4	-			860
Copper	+20	22	5.96	8		32.8
	-180	35.6	8			34.6
Nickel	+20	46	17.2	0.08	87	2.1
	-180	68.6	19.6			2.2
Iron	+20	36	28.1	0.1	109	4.8
	-196	75.5	74			0
Zinc	+20	15	-	0.8	54	109.6
	-196	9.6	-			1.8

Figure 2. Character of cavitation damage of lead in oxygen, X200.

As is indicated by the view of the erosion zone in copper (Figure 3, a, b), damage to copper occurs after considerable plastic deformation. The erosion zone produced in both liquids in nickel appears to be analogous; its resistance is much higher than that of copper. This can be explained by the greater hardening of nickel during microshock action [3], as well as by its greater tensile strength and yield point in comparison with copper (see table).

The rate of erosion was estimated for sections of equal damage (see Figure 1); values obtained are given in the table. On the basis of data on the erosion rate of lead, copper and nickel, taking into account the increased

mechanical characteristics of the metals upon cooling, it can be concluded that oxygen has a stronger microshock effect than water (increase of cavitation resistance with an increase of hardness of metals of the same type was established [6]).

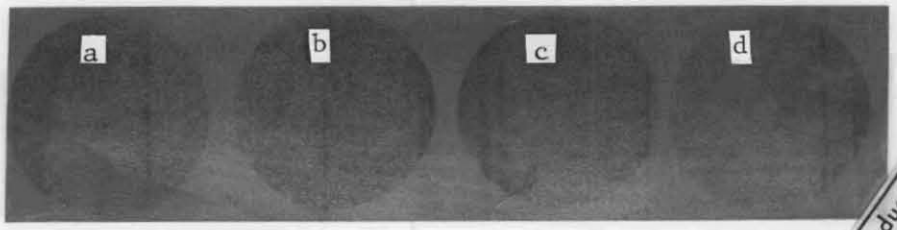


Figure 3. Form of erosion zone (X3) during cavitation action:

a - oxygen on copper (two hours); b - water on copper (two hours); c - oxygen on zinc (four hours); d - water on zinc (two hours).

As can be seen from Figure 1 and Figure 3, c, d, cavitation resistance of zinc and iron in oxygen is higher than in water; the resistance of these metals to the cavitation action of oxygen is much higher than that of copper or even nickel. These facts can be explained if one considers that copper and nickel, when cooled, retain their capacity for plastic deformation, but zinc and iron become brittle. This agrees with the conclusion [3] that plastic deformation of material contributes to cavitation damage.

As is known, cavitation erosion of materials in water is the result of the joint action of microshocks and the intensive oxidation of the surface of the metal. During the cavitation action of oxygen, not one of the metals studied was oxidized, which was probably due to their low temperature.

CONCLUSIONS

/217

1. Materials which remain plastic when cooled to -196° C are less resistant to the cavitation effect of oxygen (over a period of four hours at a vibration amplitude of 15 μ) than brittle materials.

2. Degassing liquid oxygen causes the microshock effect of oxygen to exceed that of water.

3. There is no corrosion of materials in the cavitation action of oxygen, making it possible to study more extensively the role of the mechanical factor of cavitation.

REFERENCES

1. Bebchuk, A.S. Akusticheskiy zhurnal, Vol. 1, 1957, p. 90.

2. Hemmit, F.G. Works of the American Society of Mechanical Engineers, Vol. 3, 1963, p. 16.

3. Bogachev, I.N. and R.I. Mintz. Povyshenyye kavitatsionno-erozionnoy stoykosti detaley machin (Increasing Cavitation-Erosion Resistance of Machine Parts). "Mashinostroyeniye" Press, 1964.

4. Feed, P.L. The Properties of Metallic Materials at Low Temperatures, London, 1952.

5. McCammon, R.D. and H.M. Rosenberg. Proc. Roy. Soc., Vol. A242, 1957, p. 203.

6. Gavranek, V.V. Trudy Khar'kovskovo politekhnicheskovo in-ta. Seriya metallurgicheskaya. Vol. 9, 1957, p. 61.

Translated for National Aeronautics and Space Administration under Contract No. NASw 2035, by SCITRAN, P.O. Box 5456, Santa Barbara, California, 93108.